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Wind Data from Kennedy Airport

Research and Special Programs Administration
John A. Volpe
National Transportation Systems Center
Cambridge, MA 02142-1093

Final Report
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13. ABSTRACT (Maximum 200 words)
A 700-foot array of horizontal and vertical single-axis anemometers was installed at New York's Kennedy Airport on 30-foot poles under the approach to Runway 31R. One-minute average measurements were recorded continuously, with a few breaks, from September 1994 through June 1995. Although the original purpose for the anemometers was to track the lateral position of wake vortices, the measurements also provide a database of wind and turbulence that can be used for other purposes. For example, the crosswind data has been used to evaluate four adaptive wake vortex separation systems based on the measured crosswind. This report documents the data formats and database characteristics and provides information on how to obtain a copy of the data.

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PREFACE

One of the long-term goals of the United States Wake Vortex Program is to develop systems that adapt wake-vortex separations to changes in circumstances, such as meteorology, which would affect the risk of a wake-vortex encounter. A number of systems based on crosswind measurements have been developed in the United States, Germany, and elsewhere. The purpose of this report is to provide a wind data set that can be used to evaluate such systems.

The Federal Aviation Administration (FAA) Wake Vortex Program Manager, George C. (Cliff) Hay, has asked the John A. Volpe National Transportation Systems Center (Volpe Center) to make its extensive archives of wake vortex data available in electronic form for wake vortex research. This report is the first in a series that will document available data and make it available on CD ROM to interested parties. The CD ROM can be obtained by contacting the Volpe Center library.

The authors would like to acknowledge the support of Leo Jacobs, who helped install and maintain the Kennedy test site, and David Hazen, who managed and validated the data files coming from the site and the surface observations. Both are employees of the System Resources Corporation. Jim Hallock of the Volpe Center reviewed the report and assisted in getting it published.

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (ha) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

°C=5/9(°F - 32)

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

°F=9/5(°C) + 32

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES	0			1		2			3		4			5
CENTIMETERS	0	1	2	3	4	5	6	7	8	9	10	11	12	13

QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10286.

Updated 8/1/96

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

1. INTRODUCTION

In 1994, the John A. Volpe National Transportation Systems Center installed a ground-wind wake vortex tracking system[1] at New York's Kennedy Airport at the same Runway 31R approach region used for testing[2] in the 1970s. The new installation consisted[3] of an array of two-axis anemometers (vertical wind and crosswind). The headwind was also measured at the ends of the array. The data collection system operated automatically and generated data files of one-minute averages, with standard deviations, of all anemometers. Temperature and relative humidity were also measured.

The wind data collected from September 1994 through June 1995 will be presented in this report. The data collection was continuous during this period with some missing blocks of data. The most significant missing data gaps are four weeks in December-January and one week in early March. This data set was used to analyze four crosswind adaptive separation systems; the methodology and results are presented in Appendix A. Appendix B contains the programs used in the analysis.

The purpose of this report is to make the wind data set available to other researchers. Chapter 2 describes the data collection, and Chapter 3 the data processing. Chapter 3 also presents the headwind and crosswind distributions and the day-by-day data availability for the data set. Chapter 4 describes the databases provided on the available CD ROM; which can be obtained by contacting the Volpe Center Library (617-494-2306).

2. DATA COLLECTION

2.1 DATA DIGITIZATION

2.1.1 Sensor Descriptions

The sensors listed in Table 1 were digitized by four Campbell Scientific data acquisition systems (CSDAS #n, n=1-4). CSDAS #1-3 report in low-resolution binary format (two bytes per channel).

Table 1. Sensors Recorded

Sensors	Units	Number	Total Channels
Two-Axis Anemometers	m/s	17	34
Three-Axis Anemometers	m/s	2	6
Temperature	°C	1	1
Humidity	%	1	1
Noise	0.1 volt	1	1
TOTAL		22	43

CSDAS #4 reports in ASCII format. The first three CSDAS sample the sensors at 10 Hz and report two-second averages every two seconds. Since the three CSDAS may not be synchronized, the data acquisition system prefixes the second the message was detected (to hundredths of a second) in standard Campbell low resolution format. Since the message channels are scanned every half second, the actual resolution on the message time tags is only 1/2 second (not the 1/18 second resolution of the computer clock). The wind units are meters/second. The aircraft A/C noise units are 0.1 volts.

The anemometers were installed at approximately 30-foot height on 19 fiberglass poles at locations given in Table 2. The three-axis anemometers measure crosswind, vertical wind and headwind. The two-axis anemometers measure crosswind and vertical wind. The sign convention is defined with respect to a pilot landing on Runway 31R; positive lateral distances and crosswinds are toward the pilot's right hand. The distances from the middle marker are toward the runway. The temperature, relative humidity and aircraft noise sensors were installed near the runway centerline on the main anemometer line, 400 feet from the middle marker.

Table 2. Anemometer Pole Locations

Pole	Distance (ft) from Runway Centerline	Distance (ft) from Middle Marker	Number Axes
01	-350	400	3
02	-300	400	2
03	-250	400	2
04	-200	400	2
05	-150	400	2
06	-100	400	2
07	-50	400	2
08	0	400	2
09	50	400	2
10	100	400	2
11	150	400	2
12	200	400	2
13	250	400	2
14	300	400	2
15	350	400	3
16	0	450	2
17	50	450	2
18	0	200	2
19	50	200	2

The single-axis propeller anemometers were manufactured by the R. M. Young Company with a current Model No. of 27106R. The four-bladed propellers are made of black polypropylene, have

a distance constant of 2.7 meters and a starting speed of 0.5 m/s, and have an approximate cosine wind response. The calibration of each anemometer was checked for nominal response (17.2 m/s per Volt).

2.1.2 Parameter Names

Table 3 describes the channel assignment. The 3 or 4 letter codes assigned to each sensor are included. The anemometer axes are labeled Cnn, Vnn or Hnn, where nn refers to the pole number and C, V or H refer to crosswind, vertical wind or headwind, respectively. The names of the standard deviation parameters are obtained by prefixing a "T" for turbulence, e.g. , TVnn. Note that, according to Monin-Obukhof similarity theory, TVnn is a better indication of atmospheric turbulence in the boundary layer than TCnn or THnn, which are influenced by large scale eddies which affect the wind direction.

Since space was available in the output format for CSDAS #3, standard deviations were calculated on the 20 samples in the 2-second average for the 2-second averaged data in channels 1-7. These standard deviations were found to be very small (less than half the one-minute standard deviation for vertical wind components and less than one third the one-minute standard deviation for horizontal wind components) and have been excluded from all subsequent analyses.

Table 3. Data Acquisition System Channel Assignments, Parameter Names

Channel	CSDAS #1		CSDAS #2		CSDAS #3		CSDAS #4
0	ID=1		ID=2		ID=3		ID=4
	Main Baseline, 400 ft from MM						
	Crosswind		Vertical Wind				
1	-300 ft	C02	-300 ft	V02	A/C Noise	ACNO	Temperature TMPC
2	-250 ft	C03	-250 ft	V03	Cross -350 ft	C01	Rel. Humid. HUMD
3	-200 ft	C04	-200 ft	V04	Vert -350 ft	V01	
4	-150 ft	C05	-150 ft	V05	Head -350 ft	H01	
5	-100 ft	C06	-100 ft	V06	Cross 350 ft	C15	
6	-50 ft	C07	-50 ft	V07	Vert 350 ft	V15	
7	0 ft	C08	0 ft	V08	Head 350 ft	H15	
8	50 ft	C09	50 ft	V09	50 ft Cross, 200 ft baseline	C19	
9	100 ft	C10	100 ft	V10	50 ft Vert, 200 ft baseline	V19	
10	150 ft	C11	150 ft	V11	Std Dev Ch 1	VACN	
11	200 ft	C12	200 ft	V12	Std Dev Ch 2	SC01	
12	250 ft	C13	250 ft	V13	Std Dev Ch 3	SV01	
13	300 ft	C14	300 ft	V14	Std Dev Ch 4	SH01	
	Baseline 450 ft from MM						
14	0 ft	C16	0 ft	V16	Std Dev Ch 5	SC15	
15	50 ft	C17	50 ft	V17	Std Dev Ch 6	SV15	
	Baseline 200 ft from MM						
16	0 ft	C18	0 ft	V18	Std Dev Ch 7	SH15	

2.2 DATA ACQUISITION

The primary data acquisition system (DAS) is hosted in an industrial PC and was derived from an available weather acquisition system. The DAS accepts data from up to 32 serial ports. The DAS software operates under the Desqview multitasking environment. The DAS operating

information is specified in a configuration file, which defines the message format and storage requirements for each serial channel.

2.2.1 Equipment Layout

The four CSDAS were located in a small shelter near the middle of the anemometer array to minimize cable lengths. The DAS was installed in a trailer located near the end of the anemometer array and was one node in a Novell Netware computer network. The network permitted real-time analysis of the data from the anemometer array.

The primary purpose of the anemometer array was to track wake vortices generated by aircraft landing on Runway 31R. The use of the same anemometers to sense ambient wind conditions was auxiliary to this main purpose. In fact, the wake vortices pose a data processing problem since they can corrupt the ambient wind data (see Section 3.2). The following three sections describe the various files recorded by the DAS. The second one was used for the wind analysis of this report.

2.2.2 Raw Wake Vortex Data Storage

The daily data file is named "WMmmDdd.Yyy," where the capital letters are fixed in the file name and mm is the month, dd is the day and yy is the year. This file stores one-minute data blocks and is saved on both the local DAS hard drive and the network fileserver. The configuration file used each day is copied to a file named "XMmmDdd.Yyy." Because of the amount of two-second averaged data, the complete WM file for one day contain more than 4 Mbytes. To reduce this file size by eliminating uninteresting data, two options were specified for the amount of data saved in the WM file: (a) all data, or (b) the minute before and four minutes after each aircraft arrival, which was detected by measuring aircraft noise near the middle of the main anemometer array.

2.2.3 Meteorological Data Storage

A secondary data acquisition program receives each one-minute data block as a mail message (under Desqview) from the primary data acquisition program. It saves the non-binary data as received, but processes the two-second binary data into one-minute means and standard deviations, which are stored as ASCII. The meteorological file is named DMmmDdd.Yyy and stores all one-minute data blocks for the day. It is recorded on both the local hard drive and the network fileserver. The configuration file for this file is named CMmmDdd.Yyy and was generated by manually editing the file XMmmDdd.Yyy rather than by automatic computer processing, since it was fixed for long periods of time.

2.2.4 Real-Time Analysis

The data collection program also outputs three files to the network fileserver that can be used for real-time analysis.

2.2.5 Clock Time

The data collection clock time was defined by the clock on the fileserver. This clock was set for Greenwich Mean Time (GMT). However, a PC's clock can drift significantly and the actual time was observed to err by as much as 20 minutes. This time drift was not documented, but could affect comparisons of wind data with surface observations (Section 2.4). The surface observations should, however, give a satisfactory indication of the general meteorological conditions for the detailed wind measurements.

2.3 KNOWN SENSOR FAILURES

1. During the period when the data collection system was down (12/16/94 - 1/13/95), anemometer V08 vibrated loose and fell off its pole.

2. On 2/25/95 pole 09 fell down, thereby disabling C09 and V09.

3. On 2/26/95 V02 seized up and stopped working. It had earlier showed signs of a high starting threshold.

These failures were corrected on 3/9-10/95.

2.4 SURFACE WEATHER OBSERVATIONS

The surface observations were obtained from Weather Services, Inc. (WSI) on a daily basis. Weekend data collection was automated, but sometimes failed. Consequently, some surface observations are missing. The surface observations also use GMT.

3. DATA PROCESSING

3.1 DATA REDUCTION

The daily DM ASCII meteorological data files are processed into a binary performance file for each day; the file name is ONyymmdd. hhm, where yy is the year, mm is the month, dd is the day and hhm is the hour and tens of minutes for the first record in the file. The performance files are included on the CD ROM and can be plotted and analyzed using standardized software (see Appendix C). The files for each month were combined into a large performance file containing all the data for a month (not included on CD ROM). Database files were then generated by selecting parameters from the performance file for output, with date and time, into comma-separated ASCII files. The file formats provided are described in Chapter 4.

The complete daily WM data files (4.9 Mbytes) were converted directly to comma-separated ASCII format (17.0 Mbytes). The conversion process retained all valid two-second messages and could therefore lead to some time anomalies if one CSDAS had more messages than another. The large size of these data files made validation impossible. They have not been analyzed in any way.

3.2 WIND SELECTION

The estimate for the ambient wind and turbulence (standard deviation of vertical wind) was selected from one end of the array (pole 1 or pole 15). To avoid the influence of wake vortices on the measurement, the pole selected was upwind with respect to the crosswind. The crosswind direction was determined by taking the sign of the sum of the one-minute average crosswinds on the two ends of the array. The following Paradox v4.0 script was used for this calculation. It also generates integer values of crosswind, headwind and windspeed.

```
CLEARALL
EDIT "MAY95A"
SCAN
  CP=[C15]
  CN=[C01]
  IF (CP > -25) AND (CN > -25) THEN
    IF (CN+CP > 0) THEN
      [CROSS]=CN
      [HEAD]=[H01]
      [TURB]=[TV01]
    ELSE
      [CROSS]=CP
      [HEAD]=[H15]
      [TURB]=[TV15]
    ENDIF
    [SPEED]=SQRT([CROSS]*[CROSS]+[HEAD]*[HEAD])
    [CI]=ROUND([CROSS],0)
    [HI]=ROUND([HEAD],0)
    [SI]=ROUND([SPEED],0)
```

```
ENDIF
ENDSCAN
DO_IT!
```

3.3 RECORD VALIDATION

Outliers in the wind record were detected by generating histograms of integer headwind and crosswind. Any values not continuous with the distribution were eliminated (only for files named "mmmyyG.TXT," which are described in Table 9 on page 18). The observed wind distributions are listed in the following section.

3.4 WIND DISTRIBUTIONS

This section presents in Figures 1-20 the headwind and crosswind distributions for the ten months of the data set. The crosswind distributions typically show a dip at zero crosswind (-0.5 to 0.5 m/s); this result is surprising since the crosswind is identically zero in many cases because of anemometer stalling. If stalling were frequent, one might expect a peak rather than a dip at zero crosswind. The zero crosswind dip is not a round-off effect; the Paradox ROUND function, which was used to generate the integer wind values, accurately selects the nearest integer (however, with variable results when the value is exactly between integers).

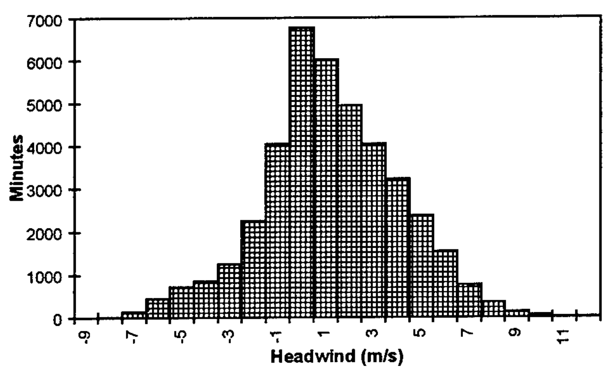

Figure 1. Headwind Distribution, Sep-94

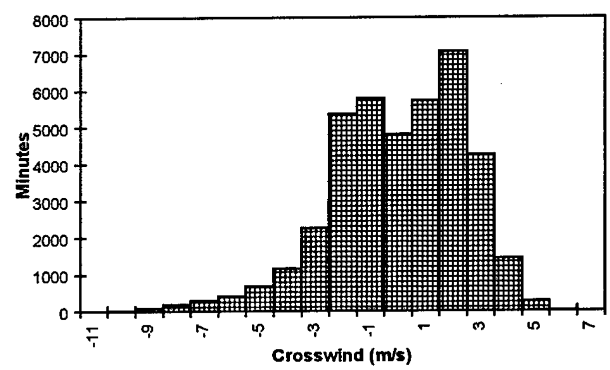

Figure 2. Crosswind Distribution, Sep-94

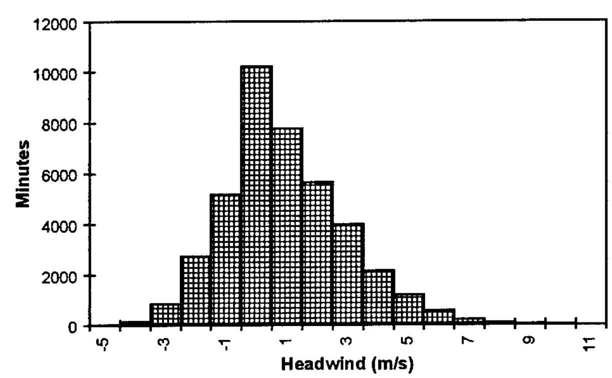

Figure 3. Headwind Distribution, Oct-94

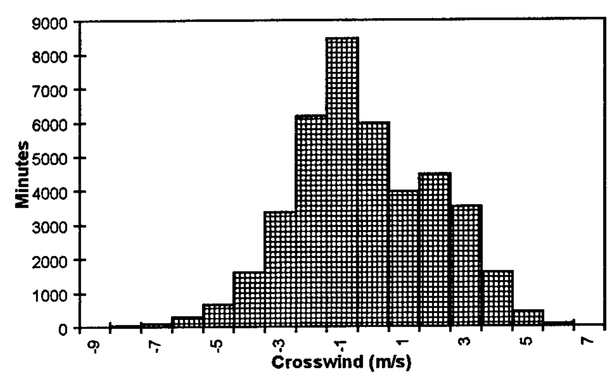

Figure 4. Crosswind Distribution, Oct-94

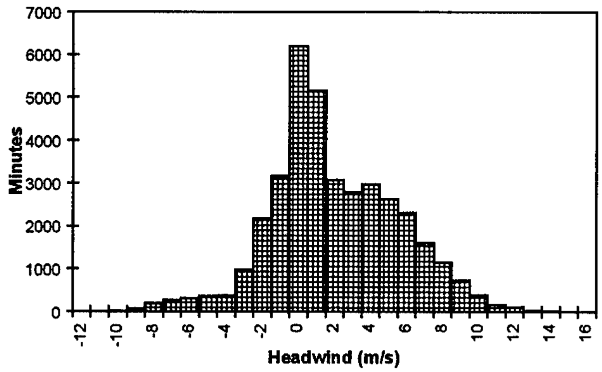

Figure 5. Headwind Distribution, Nov-94

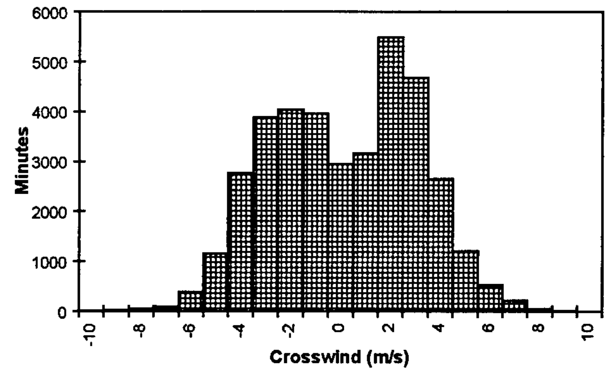

Figure 6. Crosswind Distribution, Nov-94

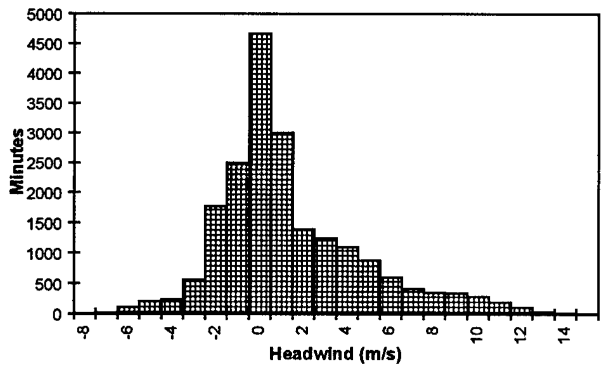

Figure 7. Headwind Distribution, Dec-94

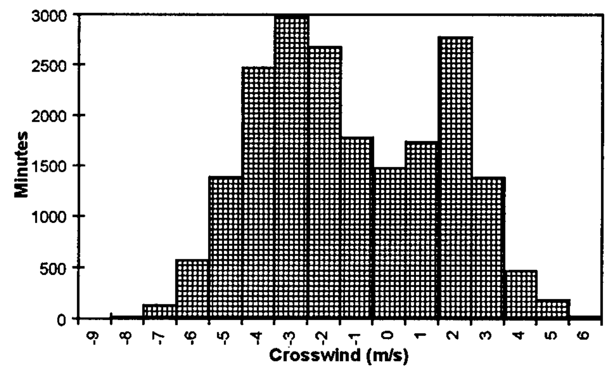

Figure 8. Crosswind Distribution, Dec-94

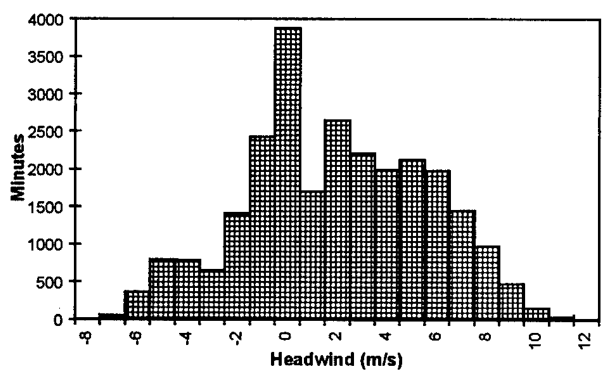

Figure 9. Headwind Distribution, Jan-95

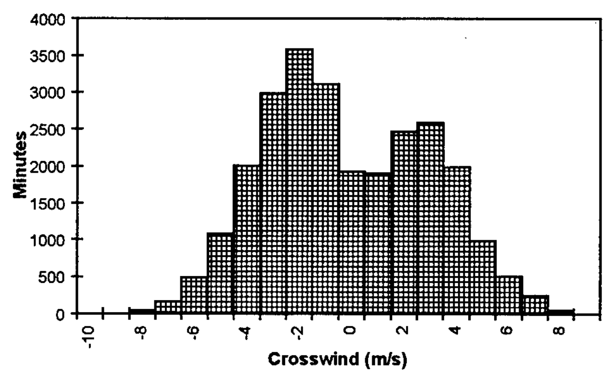

Figure 10. Crosswind Distribution, Jan-95

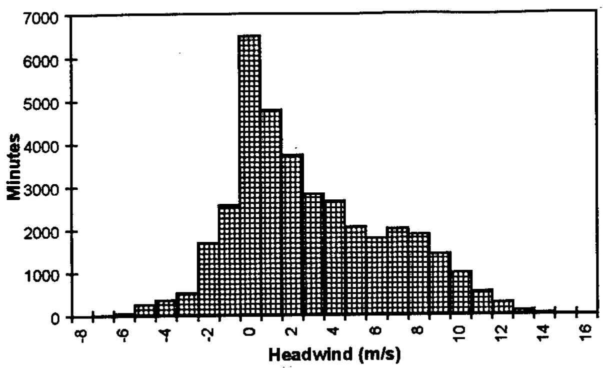

Figure 11. Headwind Distribution, Feb-95

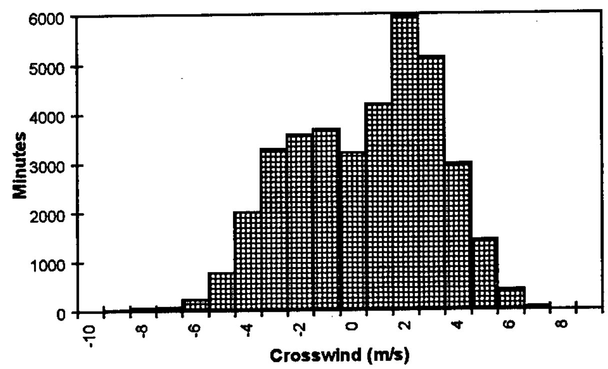

Figure 12. Crosswind Distribution, Feb-95

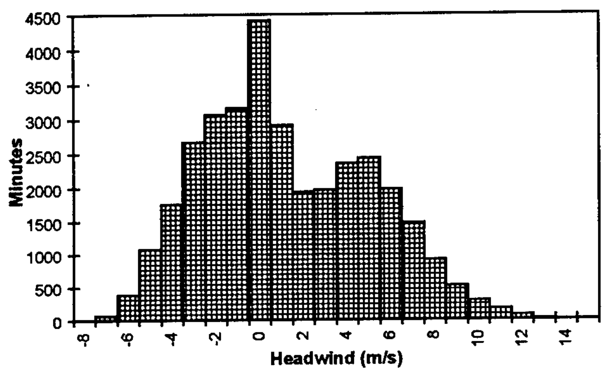

Figure 13. Headwind Distribution, Mar-95

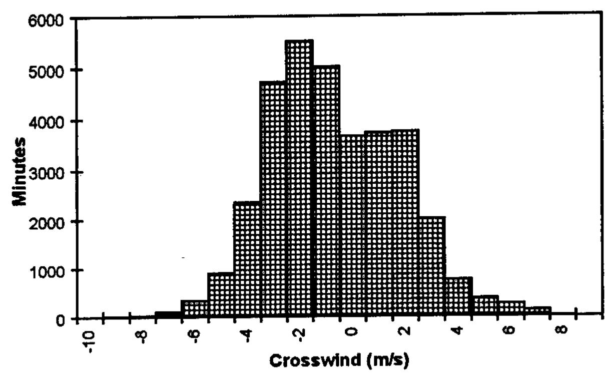

Figure 14. Crosswind Distribution, Mar-95

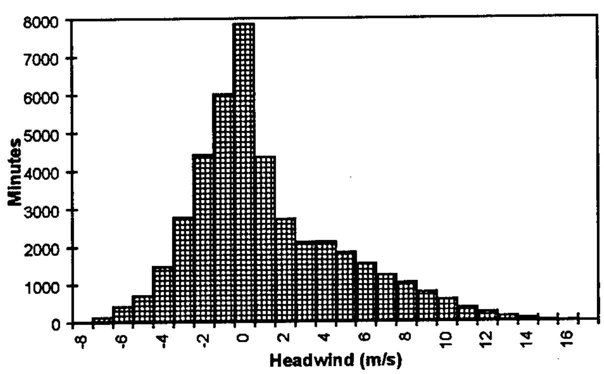

Figure 15. Headwind Distribution, Apr-95

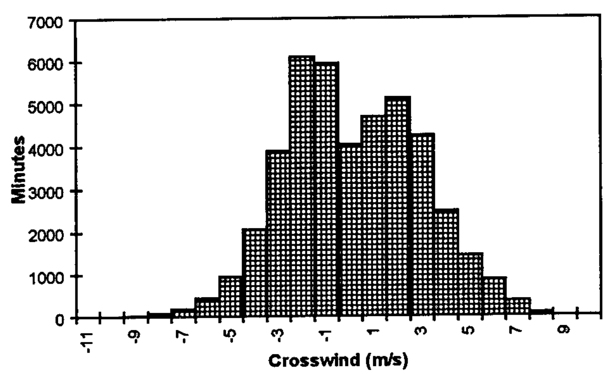

Figure 16. Crosswind Distribution, Apr-95

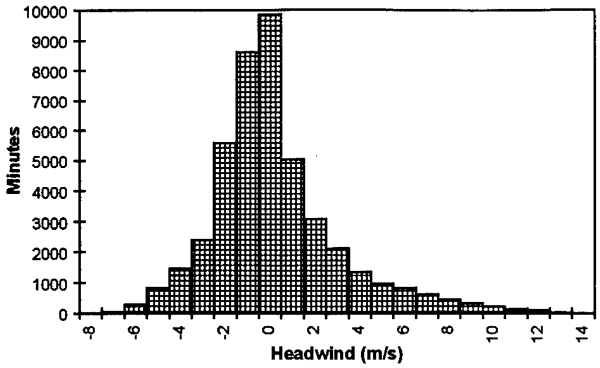

Figure 17. Headwind Distribution, May-95

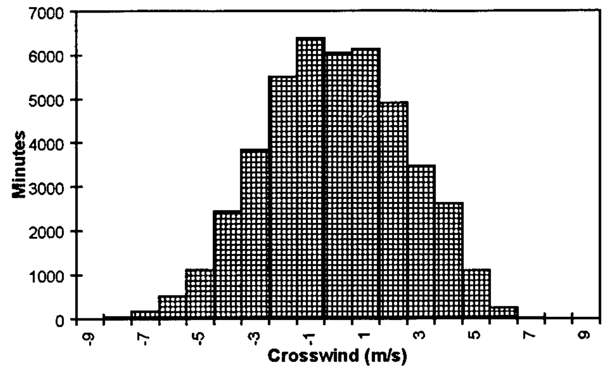

Figure 18. Crosswind Distribution, May-95

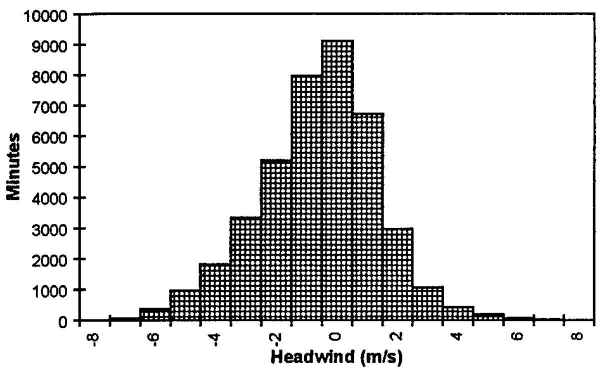

Figure 19. Headwind Distribution, Jun-95

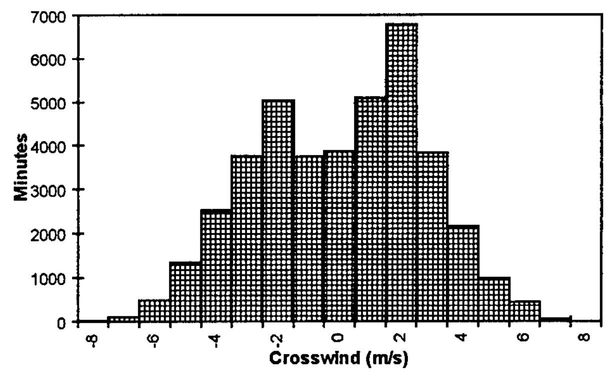

Figure 20. Crosswind Distribution, Jun-95

3.5 DATA AVAILABILITY

Table 4 shows the number of valid data minutes for each day of the data collection period. The total number of minutes in a day is 1440; the valid data minutes are always less than the 1440 because of the time taken at midnight to close the file for the previous day and open the new file for the next day.

Table 4 shows when data are missing. The biggest data gap is from December 16 through January 13, when the data collection system failed. The second biggest gap is in early March, 1995. A number of smaller data gaps are also noted. On June 29, 1995, the data collection system was removed for subsequent installation at the Memphis, TN, airport. The percentage data availability by month is shown at the bottom of the table.

Table 4. Minutes of Data per Day

Day	Sep-94	Oct-94	Nov-94	Dec-94	Jan-95	Feb-95	Mar-95	Apr-95	May-95	Jun-95
1	1425	900	479	1170	0	1425	650	1436	1435	1436
2	1425	1423	1421	365	0	1427	0	1437	1436	1436
3	1422	1422	1421	1423	0	1426	0	1437	1436	1436
4	1425	1422	1420	1426	0	1427	0	1437	1436	1436
5	1424	1191	788	1426	0	1426	0	1437	1436	1436
6	1422	1422	0	1426	0	1427	0	1437	1436	1436
7	1422	1422	0	1428	0	1426	0	1437	1436	1436
8	1424	1421	473	1423	0	1427	548	1437	1436	1436
9	1427	1422	1421	1427	0	1426	817	1437	1436	1436
10	1425	1421	1422	1425	0	1427	1437	1437	1436	1436
11	1423	1422	1421	1426	0	1426	1437	1437	1436	1436
12	1427	1423	1423	1427	0	1425	1437	1437	1436	1436
13	1424	1421	1421	1426	449	1426	1437	1436	1436	1436
14	1426	1419	1425	1426	1425	1425	1437	1437	1436	1436
15	1427	1424	1422	1426	1426	0	1436	1437	1436	1436
16	1428	1422	1419	0	1426	0	1437	1437	1436	1436
17	1423	1422	1423	0	1428	1426	1437	1306	1436	1436
18	1425	1352	1423	0	1427	1428	1437	1428	1436	1436
19	1423	1404	1423	0	1428	1427	1437	1436	1436	1436
20	1428	1391	1423	0	1427	1425	1436	1436	1436	1435
21	1225	1412	1423	0	1426	1428	1437	1436	1436	1436
22	492	1377	1420	0	1427	1428	1437	1420	1436	1436
23	1087	0	1421	0	1426	1425	1437	1436	1436	1436
24	783	518	1421	0	1426	1427	1437	1436	1435	1436
25	1421	1421	1421	0	1424	1427	1436	1436	1436	1436
26	1229	1419	1422	0	1426	1427	1437	1435	1436	1436
27	1421	1374	1423	0	1428	1428	1437	1436	1436	1436
28	1423	1419	1421	0	1426	1418	1437	1436	1436	1436
29	1425	1418	1418	0	1427		1437	1436	1436	0
30	862	1421	1421	0	1427		1437	1436	1434	0
31		1422		0	1424		1430		1429	
Total	39863	40767	37279	20070	26123	37080	33619	42939	44505	40207
Days	30	31	30	31	31	28	31	30	31	30
Percent	92	91	86	45	59	92	75	99	100	93

3.6 ALTERNATIVE WAKE-VORTEX REJECTION ALGORITHMS

Attempts were made to use vertical turbulence values to reject data contaminated with wake vortices. Appendix C shows that wake vortices can be readily identified in plots of one-minute turbulence versus time and lateral position. The analysis used the Oct-94 data. Figure 21 shows the distribution of ambient turbulence levels observed on the two ends of the anemometer array. The influence of wake vortices was eliminated by requiring that the measured crosswind at the end of the array be greater than 1.0 m/s toward the other end of the array. The distribution is similar on the two array ends; the turbulence level is slightly higher on the positive side.

The measured aircraft noise was used to select minutes with aircraft arrivals. Figure 22 shows the distribution of noise levels, averaged over one minute.

The real-time threshold for aircraft detection was set at 2 in the units of Figure 22. Noise levels from landing jet transports were typically less than 15 units and lasted for at most two or three two-second averaging periods. Therefore, the one-minute aircraft noise levels should be less than 1 unit.

The noise distribution in Figure 22 shows a band of minutes with noise between 2 and 3 units. These values are likely generated by takeoffs over the test site, for which the noise duration is considerably longer than for landing aircraft. Takeoffs are too high for the wake vortices to be detected by the anemometer array. This interpretation is confirmed by Figure 23, which shows the distribution of centerline turbulence values for these minutes. The vertical turbulence distribution is similar to the ambient turbulence level shown in Figure 21.

The minutes with noise in the band 0.4 to 1.0 units was then selected for analysis; these minutes could be expected to contain many jet transport arrivals. The vertical turbulence distributions at five locations along the array are shown in Figure 24. The distributions are similar for all five locations. The turbulence values are significantly larger than the ambient values shown in Figure 21; the turbulence where the probability drops by a factor of two increases from about 0.30 m/s in Figure 21 to 0.4-0.5 m/s in Figure 24. However, this difference is not enough to provide reliable exclusion of wake vortex effects from measurements of ambient wind and turbulence.

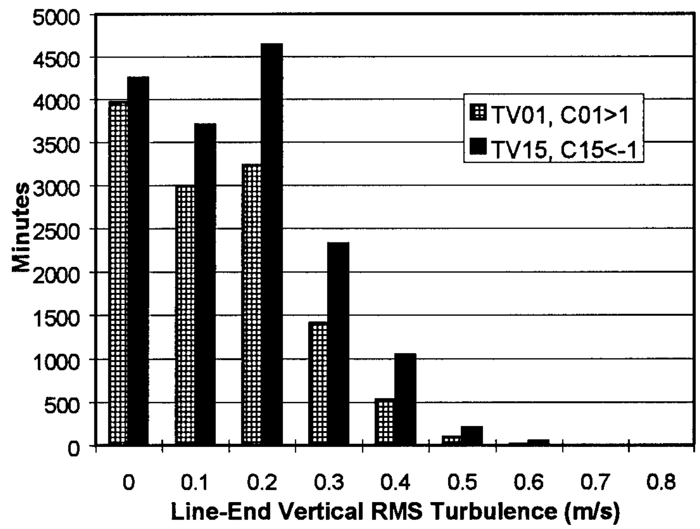

Figure 21. Distribution of Ambient Turbulence

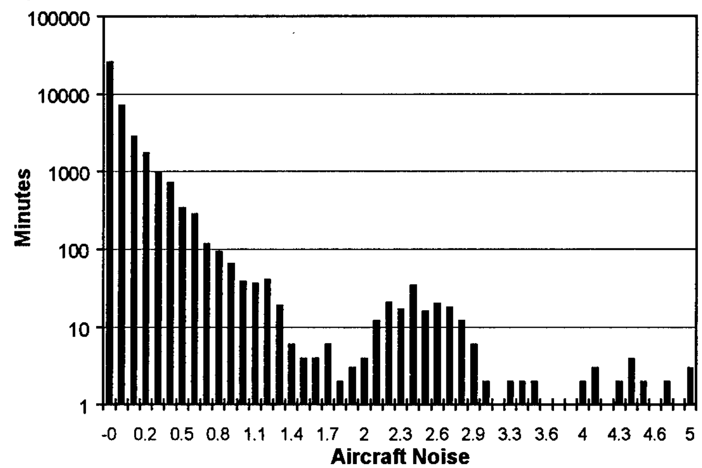

Figure 22. Distribution of One-Minute Aircraft Noise

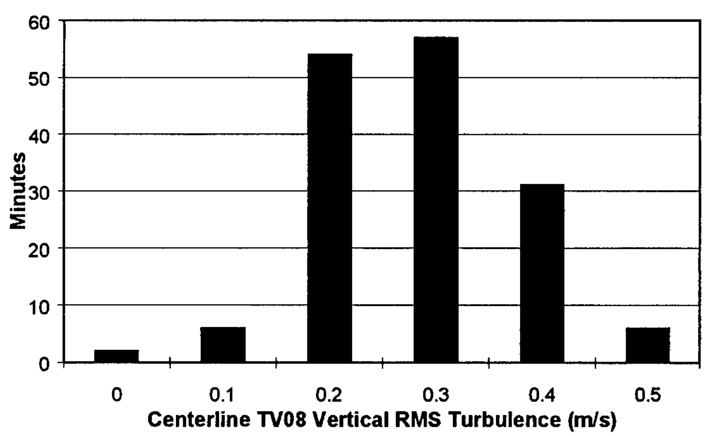

Figure 23. Vertical Turbulence on Centerline for Aircraft Noise in Band 2 to 3 units

One must conclude that, although wake vortices can generally be identified in one-minute averages of vertical turbulence, the identification is not conclusive enough to clearly screen wake vortex effects out of wind and turbulence data collected near an active runway. The ambient vertical turbulence levels are often comparable to those produced by wake vortices. Consequently, detailed tracking of wake vortices will likely be necessary to completely eliminate vortex effects from such measurements.

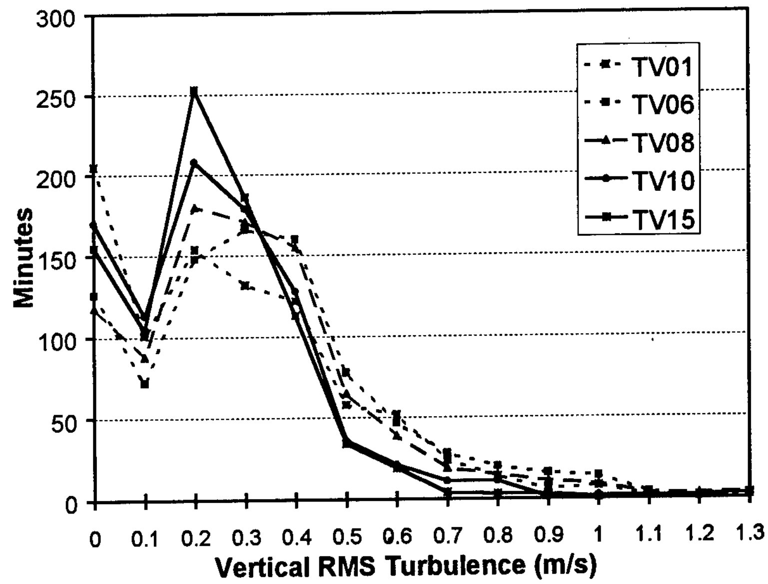

Figure 24. Vertical RMS Turbulence (m/s) at Five Locations for Noise in Band 0.4 to 1.0 Units

3.7 SURFACE WEATHER OBSERVATIONS

The format for the surface weather observations is not particularly suitable for a database. Therefore, the observations were reformatted to clearly separate the different parameters. The final format is described in Section 4.4. Table 5 lists the number of observations for each day of the test period. Note that these observations have not been thoroughly validated and should be checked for duplicate records, etc. It is possible that some records from one day have also been included in another day.

Table 5.Surface Weather Observations per Day

Day	Sep-94	Oct-94	Nov-94	Dec-94	Jan-95	Feb-95	Mar-95	Apr-95	May-95	Jun-95
1	24	25	46	24	35	21	29	23	30	24
2	24	24	26	24	31	24	23	22	28	23
3	24	24	25	24	24	24	24	19	23	10
4	24	24	24	24	24	30	25	24	22	45
5	24	24	14	33	24	25	26	22	25	24
6	24	24	21	25	22	26	31	24	24	29
7	24	24	24	27	42	26	35	23	24	31
8	24	24	24	31	24	24	36	26	24	23
9	26	25	24	26	24	24	30	34	22	24
10	23	28	29	28	24	24	22	29	30	23
11	24	23	23	36	27	24	23	22	33	28
12	24	24	24	24	36	24	24	32	35	35
13	24	24	24	28	17	24	31	39	24	21
14	24	24	24	24	47	24	28	28	16	18
15	24	14	25	26	36	32	19	21	37	24
16	30	24	24	24	47	29	33	24	28	23
17	36	23	24	33	36	20	42	24	29	24
18	28	24	35	29	29	22	21	25	38	24
19	24	24	29	24	38	17	22	31	35	23
20	24	35	24	24	45	23	21	24	24	25
21	24	30	30	24	30	34	37	26	24	25
22	24	24	23	24	20	23	24	31	22	16
23	39	31	0	24	23	24	24	16	24	27
24	29	27	0	33	21	28	21	24	24	31
25	27	23	0	30	24	24	15	22	26	19
26	29	23	8	24	24	21	23	10	34	49
27	41	24	24	24	24	30	23	21	28	35
28	26	24	35	23	10	42	22	16	24	24
29	24	24	24	24	14		23	29	32	22
30	24	24	24	24	25		8	29	28	0
31		27		24	22		22		22	

4. DATABASES

This chapter describes the databases distributed on CD ROM. All files are named by mmmyy where mmm is the month (e.g., Sep, Oct, etc.) and yy is the year (94 or 95). Missing data is signified by the value -99. 00. In addition to the ASCII data files described below, the CD ROM also contains the Borland Paradox v4.0 database tables (extension = DB), which may be useful to users of commercial relational database products.

4.1 COMPLETE FILES

Table 6 lists the 92 parameters in order for the complete comma-delimited ASCII databases, which have the extension = PRN. The complete file name is "mmmyy.PRN," where the capital letters are fixed and mmm is the three letter month abbreviation and yy is the year. Section 2.1.2 describes the parameter names. These files are generated from the recorded data directly, not exported from Paradox database tables. They, therefore, have not been filtered in any way for validity.

Table 6. List of Parameters in Files mmmyy.PRN

Year	C01	V01	H01	TC01	TV01
Month	C02	V02	H15	TC02	TV02
Day	C03	V03		TC03	TV03
Hour	C04	V04	ACNO - Aircraft Noise	TC04	TV04
Minute	C05	V05		TC05	TV05
	C06	V06	VACN - Aircraft Noise Standard	TC06	TV06
	C07	V07	Deviation	TC07	TV07
	C08	V08		TC08	TV08
	C09	V09	CSDAS #1 Count	TC09	TV09
	C10	V10		TC10	TV10
	C11	V11	CSDAS #2 Count	TC11	TV11
	C12	V12		TC12	TV12
	C13	V13	CSDAS #3 Count	TC13	TV13
	C14	V14		TC14	TV14
	C15	V15	Temperature °C	TC15	TV15
	C16	V16		TC16	TV16
	C17	V17	Relative Humidity %	TC17	TV17
	C18	V18		TC18	TV18
	C19	V19		TC19	TV19
					TH01
					TH15

4.2 PROCESSED FILES

Tables 7-9 show the formats of the three types of comma-delimited ASCII files exported from Paradox. In these tables the data are put in chronological order by keying the first five parameters (indicated by asterisk). The type of parameter is indicated as S for 16-bit signed integer and N for floating point number. The following paragraphs describe the files.

The mmmyy.TXT files are simplified versions of the complete files listed above.

Table 7. Format for Files mmmyy.TXT

Field Name	Field Type
Year	S*
Month	S*
Day	S*
Hour	S*
Minute	S*
H01	N
H15	N
C01	N
C15	N
V01	N
V15	N
TV01	N
TV02	N
TV03	N
TV04	N
TV05	N
TV06	N
TV07	N
TV08	N
TV09	N
TV10	N
TV11	N
TV12	N
TV13	N
TV14	N
TV15	N
ACNO	N
VACN	N

Table 8. Format for Files mmmyyA.TXT

Field Name	Field Type
Year	S*
Month	S*
Day	S*
Hour	S*
Minute	S*
H01	N
H15	N
C01	N
C15	N
V01	N
V15	N
TV01	N
TV02	N
TV03	N
TV04	N
TV05	N
TV06	N
TV07	N
TV08	N
TV09	N
TV10	N
TV11	N
TV12	N
TV13	N
TV14	N
TV15	N
ACNO	N
VACN	N
Cross	N
Head	N
Speed	N
Turb	N
Ci	S
Hi	S
Si	S

Table 9. Format for Files mmmyyG.TXT

Field Name	Field Type
Year	S*
Month	S*
Day	S*
Hour	S*
Minute	S*
Cross	N
Head	N
Speed	N
Turb	N
Ci	S
Hi	S
Si	S

The mmmyyA.TXT files have the following additional calculated parameters: crosswind, headwind, windspeed and turbulence from the upwind side of the runway (see Section 3.2 for algorithm) and the integer values: Ci, Hi and Si for the first three parameters.

The files mmmyyG.TXT contain selected fields from mmmyyA.TXT. The records have been selected to have valid headwinds and crosswinds using the algorithm from Section 3.3.

4.3 TWO-SECOND DATA

Selected data files are provided in the two second data format mentioned in Section 3.1; the WM file name is changed to have an extension of PRN instead of the year. The file selection was based on available complete WM data files and the available space on the CD ROM. The files are provided in self-extracting .EXE files to conserve CD ROM space.

Table 10. List of Parameters in Files WMmmDdd.PRN

Header	CSDAS # 1	CSDAS #2	CSDAS #3
Year	Second	Second	Second
Month	"1"	"2"	"3"
Day	C02	V02	ACNO
Hour	C03	V03	CO1
Minute	C04	V04	V01
	C05	V05	H01
	C06	V06	C15
	C07	V07	V15
	C08	V08	H15
	C09	V09	C19
	C10	V10	V19
	C11	V11	Std. Dev. ACNO
	C12	V12	Std. Dev. CO1
	C13	V13	Std. Dev. V01
	C14	V14	Std. Dev.H01
	C16	V16	Std. Dev. C15
	C17	V17	Std. Dev. V15
	C18	V18	Std. Dev. H15

The parameters in the two-second files are listed in Table 10. The format is essentially the same as that of the data collection, as listed in Table 3.

4.4 SURFACE OBSERVATION FILES

The monthly Surface Aviation Observation (SAO) files are named "JFKyymm.TXT," where the capital letters are fixed and yy is the year and mm is the month. A sample record is shown, with the field numbers below:

JFK","SA",94,6,29,17,50,29.84,72,66, 28,
11,,,6,"",2,"SCT",24,"BKN",40,"OVC","E","TRW-","H"
(1) (2) (3)(4)(5)(6)(7) (8) (9)(10)(11)(12)(15)(17) (18) (19) (20) (21) (22) (23) (24)
(25)

The fields in order are:

1. 'Site' - Site Code, where 'JFK' means John F. Kennedy International Airport, New York City, NY
2. 'Rtype' - Report type:

   SA - Surface Aviation, issued hourly

   SP - Special Observation

   RS - Record Special observation, issued hourly but meets criterion for 'SP'.
3. 'Year'
4. 'Month'
5. 'Day'
6. 'Hour'

7. ‘Minute’
8. ‘Alts’ - Altimeter setting in inches Hg
9. 'Temp' - Temperature in degrees Fahrenheit
10. 'Dewpt' - Dewpoint in degrees Fahrenheit
11. 'Wdir' - Wind direction in degrees
12. 'Wspd' - Wind speed in knots
13. 'Wchar' - Wind character (gust) in knots. Blank if none is reported.
14. 'Paccum' - Precipitation accumulation in inches. This field is always blank because precipitation amounts are given in the remarks every 6 or 12 hours.
15. 'Hvis' - Horizontal visibility in miles
16. 'Obscur' - Sky obscuration (-X is partial obscuration, W is indeterminate ceiling, X is full obscuration). Blank if none.
17. 'Cbh1' - Cloud base height of layer 1 in hundreds of feet. Blank if 'Cc1' field is 'CLR'.
18. 'Cc1' - Cloud cover of layer 1 (CLR is clear, SCT is scattered, BKN is broken, OVC is overcast, minus sign in front means thin.)
19. 'Cbh2' - Cloud base height of layer 2 in hundreds of feet. Blank if 'Cc1'= CLR.
20. 'Cc2' - Cloud cover of layer 2. Blank if 'Cc1'= CLR.
21. 'Cbh3' - Cloud base height of layer 3 in hundreds of feet. Blank if 'Cc1'= CLR.
22. 'Cc3' - Cloud cover of layer 3. Blank if 'Cc1'= CLR.
23. 'ClgD' - Cloud base height determination method, for example, M = measured, E = Estimated. Blank if 'Cc1'= CLR.
24. 'Prwx' - Present weather. Most common are: R = rain, S = snow, L = drizzle, IP = sleet, A = hail. The letter 'T' before a precipitation type means thunderstorm. The letter 'Z' before a precipitation type (usually R or L) means freezing precipitation. A 'W' after the precipitation type means shower. Precipitation intensities are at the end of the field, with a '+' meaning heavy, a '-' meaning light and no symbol meaning moderate precipitation.
25. 'Ob2vis' - Obstruction to vision. Most common: F = fog, H = haze, BS = blowing snow

APPENDIX A - ANALYSIS OF FOUR CROSSWIND-BASED ADAPTIVE SEPARATION SYSTEMS

This paper was presented as a poster at the Seventh Conference on Aviation, Range and Aerospace Meteorology, February 2-7, 1997, in Long Beach, CA. It is being submitted to the *Journal of Aircraft* for formal publication.

P3.1

CROSSWIND MEASUREMENT AND FORECASTING REQUIREMENTS FOR AIRCRAFT WAKE VORTEX AVOIDANCE SYSTEMS

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1. INTRODUCTION

Systems have been designed to permit reduced wake-vortex separations, and hence increased airport capacity, under appropriate crosswind conditions. Different systems were designed for landing operations on a single runway and on close-spaced parallel runways (less than 2500 feet apart).

1.1 Single Runway System

For a single runway, a crosswind above a certain value will remove all wake vortices from the approach region before the arrival of the next aircraft. The single runway system concept, termed the Vortex Advisory System (VAS), was developed in the United States in the late 1970s (see Spitzer, 1977).

The VAS algorithm (see Hallock, 1977) defines a wind ellipse (with crosswind minor axis of 2.9 m/s or 5.5 knots and headwind major axis of 6.2 m/s or 12 knots). When the wind vector is outside this ellipse wake vortices were not seen to last more than 80 seconds inside an approach safety corridor of ±46 meters from the runway centerline. At normal approach speeds this time corresponds to the normal radar separation of 3 nautical miles (NM). Thus, whenever the wind vector is outside this ellipse, the 3-NM longitudinal separation can be safely used, instead of the 4-, 5- or 6-NM separations required for some classes of aircraft.

The crosswind portion of the VAS algorithm is based on the wake vortices being transported out of the safety corridor. The headwind portion of the VAS algorithm is based on the faster vortex decay to be expected for higher wind speeds; this faster decay is expected from the higher turbulence levels associated with higher wind speeds. Since turbulence will also raise the vortex detection threshold for the sensor used to measure the vortex residence time inside the safety corridor, the headwind portion of the VAS algorithm is less certain than the crosswind portion. Therefore, this paper will use only a crosswind criterion for safety.

1.2 Parallel Runway System

For parallel runways, wake vortices may never reach the parallel runway when the cross wind is below a certain value. For larger values of cross wind, reduced separation operations may be safe if larger aircraft are assigned to the downwind runway and smaller aircraft to the upwind runway. The parallel runway system concept was developed in Germany in the 1980s (see Reichmuth, 1992).

The German parallel runway system was developed for the Frankfurt airport that has two parallel runways separated by 518 meters (1700 feet). Tetzlaff (1992) presents some of the data used to derive the limiting crosswind of 1.8 m/s or 3.5 knots, below which the wake vortices are never observed to reach the parallel runway with hazardous strength. The limiting crosswind would be greater for greater runway spacing and lower for smaller runway spacing.

The German system deals with a single stream of aircraft approaching the two runways. However, a more efficient application of a parallel runway crosswind system is to use dependent approaches to the two runways with 1.5-NM diagonal spacing. The latter approach will be adopted for this paper. Several operational conditions may apply:

1. If the crosswind is less than the limiting value, the aircraft can land alternately on the two runways. The single-runway longitudinal separation standards will have to applied to each runway separately.
2. If the crosswind is greater than the limiting value, then approximately the same runway capacity can be achieved, but only by assigning the larger aircraft to the downwind runway. The controller can prepare for this transition by making the appropriate runway assignments for the low-crosswind mode of operation. A major

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reconfiguration will then result only if the forecast sign for future large-crosswind-mode operations is incorrect.

2. SYSTEM REQUIREMENTS

Wake vortex avoidance concepts based on lateral wake vortex transport require that the cross wind criteria are satisfied (1) at all locations where wake vortex encounters may occur and (2) for a significant time into the future so that use of the reduced separations will persist long enough to contribute to increased capacity. Since changes in the landing pattern require 15-30 minutes to implement, changes in required separations must be forecast at least 30 minutes into the future to prevent disrupting operations by unscheduled pattern changes. Thus, the crosswind must be forecast at least 30 minutes ahead. However, not all crosswinds are equally important; the actual requirement is to forecast crosswind changes across wind boundaries that will require changes in the operating configuration.

The consequences of not forecasting a change in separation standards may be operationally significant. Unsheduled decreases in aircraft spacings will require one or more missed approaches which not only waste time, but also represent a lower level of safety than normal landings. An acceptable level of unscheduled increases in separation is perhaps one per day.

Controller workload considerations suggest that changes in the operating configuration must not occur more than once per hour. For example, 1-m/s guardbands were placed on the VAS ellipse to reduce the frequency of transition between the two different separation requirements. In other words, for the crosswind criterion, the closer separations are implemented only when the crosswind is above 3.9 m/s.

3. SYSTEM ANALYSES

Four crosswind systems will be analysed:

1. Single-runway system (VAS),
2. Low-wind parallel-runway system,
3. Parallel-runway system with larger aircraft assigned to only one runway (e.g., as at Boston's Logan Airport), and
4. General parallel-runway system where larger aircraft can be assigned to either runway.

3.1 Methodology

The one-minute average crosswind will be taken from measurements and used to compute the frequency of change in separation standards and the percentage of time that reduced separation standards are allowed. Guardbands will be placed on the crosswind breakpoints and adjusted in size to give less than one transition per hour. The sensitrivity of the system performance to the size of the guardband will be used to assess the impact of measurement or forecast errors on system performance.

The analysis will be conducted on a month-by-month basis and will use all the valid data in the wind database collected at New York's Kennedy airport (JFK) from September 1994 through June 1995. Future more realistic analyses could include additional data selection criteria such as:

1. Times when airport capacity is saturated,
2. Times when winds are within normal allowed operational limits (e.g., crosswind less than 7.5 m/s, tailwind less than 2.5 m/s), or
3. Times when aircraft were actually landing on the runway where the winds were measured.

3.2 Wind Database

Table 1. Monthly Statistics on JFK Wind Data

Month	Valid Data	Mean Cross-wind	Mean Head-wind	Wind Outside Limits
Sep-94	92%	0.0	1.2	11%
Oct-94	91%	-0.3	0.9	3%
Nov-94	86%	0.2	2.0	7%
Dec-94	45%	-1.1	1.4	6%
Jan-95	59%	-0.2	2.0	11%
Feb-95	92%	0.5	2.8	3%
Mar-95	75%	-0.7	1.2	18%
Apr-95	99%	0.1	1.1	13%
May-95	100%	-0.1	0.2	12%
Jun-95	93%	0.0	-0.6	16%

The wind at JFK airport was measured near the middle marker for Runway 31R using three-axis propeller anemometers at two locations ±107 meters from the extended runway centerline. One-minute averages and variances were calculated from the raw two-second-average data. In order to minimize the influence of wake vortices on the data set, the measurements selected for the analysis were taken from the upwind side of the runway. The sign of the crosswind (positive for wind blowing to the right as viewed from a landing aircraft) was determined by summing the crosswind measurements at the two locations. Outliers in the wind data were eliminated by setting monthly limits in headwind and crosswind that eliminated values not giving continuous one-meter-resolution wind distributions. The remaining percentages of valid wind data are listed by month in Table 1. The mean crosswind and headwind for the month are also listed. Most of the data losses were associated with data collection malfunctions, not the validation process. Therefore, the database consists of

almost continuous blocks of one-minute wind data, to which the system algorithms can be applied.

Runway 31R is normally used only when the winds are within suitable operational limits. Typical limits are crosswind magnitude below 7.5 m/s and tail wind less than 2.5 m/s. Column five of Table 1 shows how much of the wind data lies outside these wind limits for the months of the database. The times when the runway could not be used varied from 3 to 18 percent for different months.

3.3 *Single-Runway*

The single-runway algorithm permits 3-NM separations for all aircraft when the crosswind magnitude is greater than 2.9 m/s. A guardband is added to the algorithm to reduce the frequency of transitions between reduced 3-NM separations and normal separations. Reduced separations are initiated only when the crosswind magnitude is greater than 2.9+G m/s, where G is the guardband. Normal separations are restored when the crosswind magnitude drops below 2.9 m/s. The analysis will not consider the time required to implement a change in separation standards.

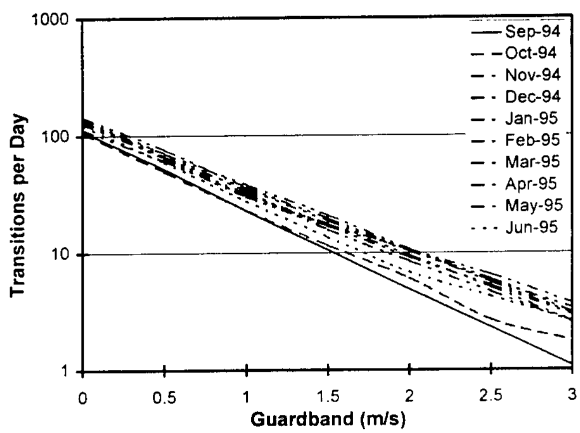

Figure 1. Transition Rate Versus Size of Guardband

The single-runway algorithm was applied by month to the JFK crosswind measurements using various guardbands. Figure 1 shows the transitions per day observed as a function of guardband value G. A transition is counted when the separation standards are either increased or decreased. The transition rate decreases exponentially with guardband value and varies relatively little with month. The acceptable level of one transition per hour (24/day) occurs for a guardband value between 1.0 and 1.5 m/s. Subsequent analysis will adopt a guardband value of 1.5 m/s. Figure 2 shows how the guardband value affects the percent of the time that reduced separations are permitted. This percentage varies by more than a factor of two for different seasons of the year; the percentage is greatest during November-January and smallest during September-October. The percentage of time for reduced separations is reduced by about one third when G is increased from 0.0 to 1.5.. Note that Hallock (1980), using the complete VAS ellipse, not just the crosswind component, obtained larger estimates of the percentage of time reduced separations would be permitted for JFK Runway 31.

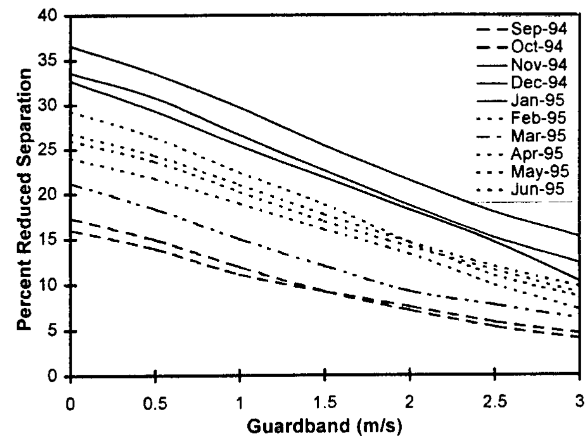

Figure 2. Percentage Reduced Separations Versus Size of Guardband

3.4 *Low-Wind Parallel Runway*

The low-wind parallel runway algorithm is the reverse of the single-runway algorithm. Wake vortices will not travel between runways if the crosswind magnitude is less than 1.8 m/s. In this case the simultaneous dependent operations can ignore the assignment of aircraft to the two runways. A guard band G is assigned to initiate the no-vortex-transport operations when the crosswind magnitude is less than 1.8-G m/s. When the crosswind becomes greater than 1.8 m/s a different operational scenario must be adopted. Note that in this operation the guardband must be less than 1.8 m/s or the no-vortex-transport operations will never start.

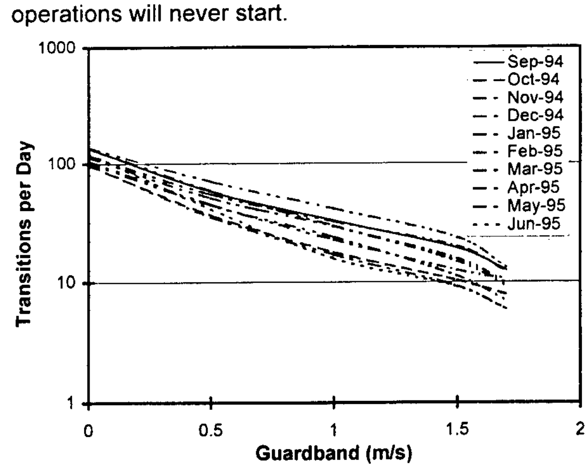

Figure 3. Transition Rate Versus Size of Guardband

Figure 3 shows the transition rate for this type of operation. As in the singie-runway case, a guard band

of about 1.5 m/s will meet the requirement of one transition per hour. Note that these guardband results extend continuously very close to the 1.8 m/s upper limit because of the high probability of the measured crosswind to be zero because of anemometer stalling.

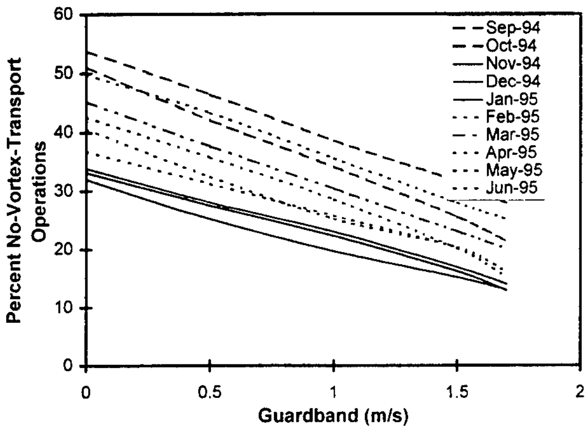

Figure 4. Percent No-Vortex-Transport Operations Versus Size of Guardband

Figure 4 shows the percentage of time for no-vortex-transport operations. Note that the percentages are larger than observed for the single-runway case in figure 2. The months showing high percentages for the parallel-runway case show low percentages for the single-runway case and vice versa. High crosswinds favor the single-runway case while low crosswinds favor the parallel-runway case.

3.5 Larger Aircraft on Only One Runway

Suppose the larger aircraft are always assigned to the right runway; then simultaneous dependent approaches are not affected by wake vortices as long as the crosswind is greater than -1.8 m/s. If the crosswind becomes less than -1.8 m/s, then dependent approaches will have to be terminated. A guard band G is assigned to initiate the simultaneous dependent operations when the crosswind is greater than -1.8 + G m/s. When the crosswind drops below -1.8 m/s dependent operations must be terminated.

Figure 5 shows the transition rate for this type of operation. As in the other cases, a guardband of about 1.5 m/s will meet the requirement of one transition per hour. The transition rate varies more for different months for this operation than for those shown in Figures 1 and 3.

Figure 6 shows the percentage of time for dependent operations. Note that the percentages are significantly larger than the no-vortex-transport operations in Figure 4. They are also reduced less by increases in the size of the guardband.

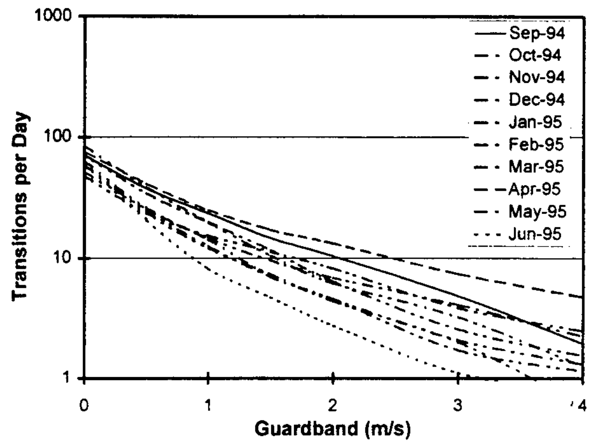

Figure 5. Transition Rate Versus Size of Guardband

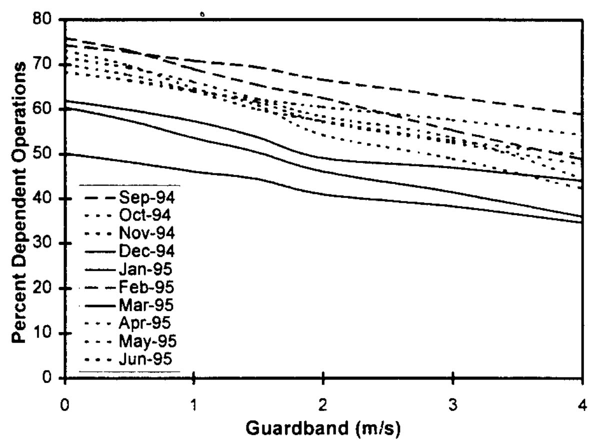

Figure 6. Percent Dependent Versus Size of Guardband

3.6 Large Aircraft on Downwind Side

If the aircraft flow could be reconfigured instantaneously, assigning heavier aircraft to the downwind side will permit dependent operations all the time. Therefore, an analysis of its effectiveness must include a runway assignment transition algorithm. In general, the controller should always assign the heavier aircraft to the downwind runway. However, he should not make the change in assignment immediately when the crosswind changes sign or he may have to reverse the assignment a short time later when the crosswind sign reverses again. Assume that the runway assignment takes ten minutes to reverse and that quicker changes will require missed approaches. This problem will arise when the one-minute crosswind becomes greater than 1.8 m/s in the wrong direction in a time too fast for the runway assignment algorithm to follow.

Two methods can be used to reduce the frequency of transition: a guardband and/or averaging the crosswind to decide when to make a transition. The crosswind is averaged for N minutes and a reversal of runway assignment is made when the wind average is

is greater than G m/s in the opposite direction from the current assignment. The goodness of the algorithm is reflected in (1) the number of transitions, the number of transitions that last for less than ten minutes and (3) the number of times the wind changes too rapidly for the runway assignment to follow.

Table 2 shows some results from this analysis for the six months with the largest fraction of valid data (see Table 1). The moderate values of 5-minute averaging and 0.5-m/s guardband were selected. The results were dramatically different for the different months. Column two of Table 2 shows the number of transitions between assigning the larger aircraft to the right or left runway. Column three shows how many of these runway assignments were ten minutes long or shorter and hence would give the controller difficulty in making the double change in runway assignment. The fourth column gives the number of "bad" minutes where the one-minute crosswind values would have required changing the heavier-aircraft runway assignment to the opposite runway. Note that this count could include more than one minute for a given transition in runway assignment. The "bad" minute count is a measure of how often the crosswind changes too rapidly for the controller to assign aircraft to the correct runway. Note that the runway assignment algorithm would work fairly well in Oct-94 and Jun-95, but very poorly in some of the other months.

Table 2. Variable Runway Assignment Results for 0.5-meter Guardband and 5-minute Average

Month	Transitions	Short	Bad Minutes
Sep-94	184	18	82
Oct-94	104	6	18
Feb-95	139	22	57
Apr-95	325	99	150
May-95	189	25	72
Jun-95	90	4	11

May-95 was selected as a typical month and examined in more detail. Figures 7-9 show how the parameters of Table 2 vary as a function of averaging time and guardband size. Figure 7 shows how the transition rate is reduced as the averaging time and guardband size are increased. Figure 8 shows that the rate of short transitions can be reduced to a negligible level if the values of averaging time and guardband size are made large enough. Unfortunately, as shown in Figure 9, increasing the averaging time and guardband size also increases the number of "bad" minutes. A better algorithm for determining runway assignment would be needed to permit simultaneous dependent operations for all months.

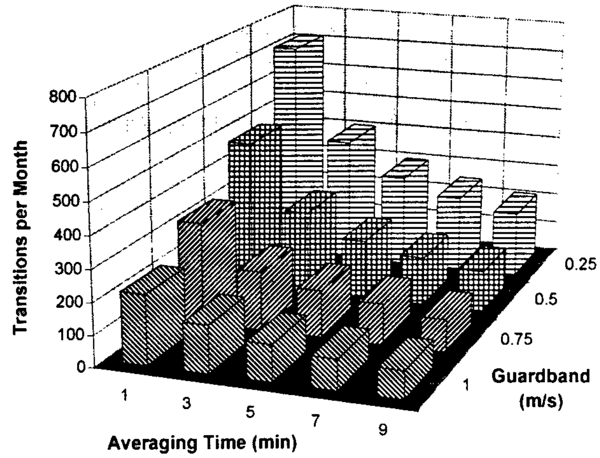

Figure 7. Transitions Versus Averaging Time and Guardband Size for May-95

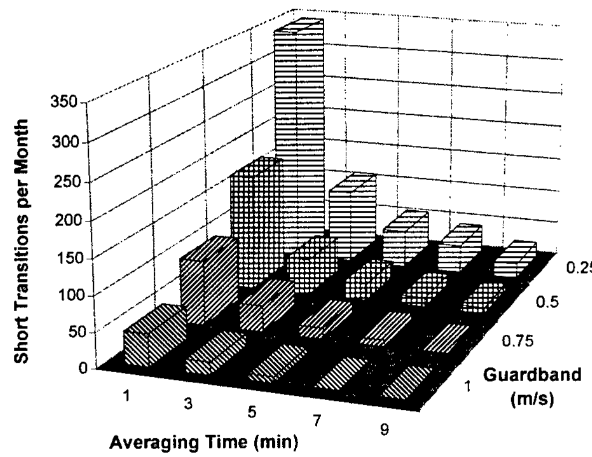

Figure 8. Short Transitions Versus Averaging Time and Guardband Size for May-95

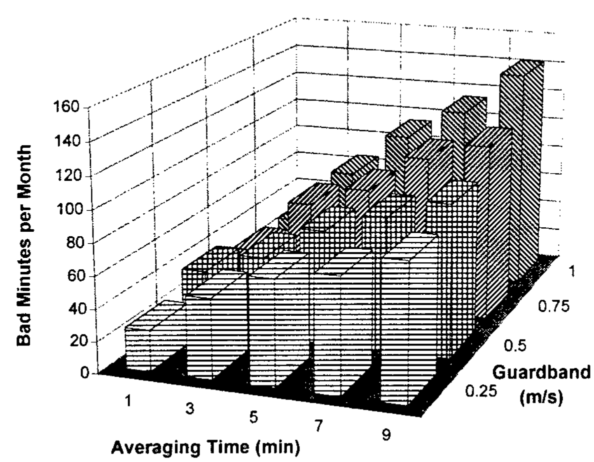

Figure 9. "Bad" Minutes Versus Averaging Time and Guardband Size for May-95

4. DISCUSSION OF RESULTS

The system algorithms described in Sections 1.1 and 1.2 were derived by analyzing vortex transport as a function of actual wind measurements. The algorithms therefore already incorporate some degree of wind measurement error. In addition to instrument errors, the amount of error depends upon the distance from the location where the wind was measured to the location where the wake vortices were measured. In general the algorithms were developed from a single wind measurement made as close to the vortex location as possible. If the algorithm is to be applied to a large portion of the approach path (e.g., from middle marker to touchdown) then either (1) multiple wind measurements will be needed or (2) a more restrictive wind limit will be needed to assure safety over the whole region.

The sensitivity of the system performance to crosswind measurement (or forecast) errors can be assessed by looking at how system performance is affected by increased guardbands. If errors are compensated by increasing the wind limit, the effect on the percentage of time for more efficient operations can be estimated by simply increasing the guardband (Figures 2, 4, and 6) by the amount of the error above the normal guardband value of perhaps 1.5 m/s. For example, consider the Nov, Dec, Jan data in Figure 2; reduced separations are permitted about 23 percent of the time for a guardband of 1.5 m/s. Additional measurement errors of 1.0 m/s would correspond to a guardband of 2.5 m/s, or reduced operations about 16 percent of the time. This reduction is noticeable but not catastrophic. In contrast, consider the effect of the same 1.0 m/s increase in error for Figure 4. A guardband of 2.5 m/s eliminates *all* no-vortex-transport operations. This mode of operation can tolerate virtually no significant increase in wind measurment error.

The analysis of Section 3.6 shows that the assumption of crosswind persistence may not be adequate to deal with changes in crosswind. A more reliable method of forecasting crosswind changes will be necessary to deal with changes in operational configurations.

ACKNOWLEDGEMENTS

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APPENDIX B - ANALYSIS SCRIPTS

The following Paradox v4. 0 scripts were used in the analyses presented in Appendix A.

VAS. SC

```
while true
@10,0 ??"Enter guardband value:"
accept "N" to guard
clearall
clear
view "may95g"
red=true
;guard=0. 5
redoffneg=-2. 9-guard
redoffpos=2. 9+guard
redonneg=-2. 9
redonpos=2. 9
trans=0
count=0
total=0
scan
  total=total+1
  if red then
    count=count+1
    if ([Cross] < redoffneg) or ([Cross] > redoffpos) then
      red=false
      trans=trans+1
    endif
  else
    if ([Cross]>redonneg) and ([Cross]<redonpos) then
      red=true
      trans=trans+1
      count=count+1
    endif
  endif
endscan
clearall
clear
@2,0 ??"Guard = ",guard," m/s"
@4,0 ??" Number of transitions = ",trans
@6,0 ??" Red Percent = ",100*count/total
@8,0 ??" Green Percent = ",100*(total-count)/total
endwhile
```

PVAS1. SC

```
while true
@10,0 ??"Enter guardband value:"
accept "N" to guard
clearall
clear
view "jun95g"
red=true
;guard=0. 5
redoffneg=-1. 8
redoffpos=1. 8
redonneg=-1. 8+guard
redonpos=1. 8-guard
trans=0
count=0
total=0
scan
  total=total+1
  if red then
    count=count+1
    if ([Cross] < redoffneg) or ([Cross] > redoffpos) then
      red=false
      trans=trans+1
    endif
  else
    if ([Cross]>redonneg) and ([Cross]<redonpos) then
      red=true
      trans=trans+1
    endif
  endif
endscan
clearall
clear
@2,0 ??"Guard = ",guard," m/s"
@4,0 ??" Number of transitions = ",trans
@6,0 ??" Red Percent = ",100*count/total
@8,0 ??" Green Percent = ",100*(total-count)/total
endwhile
```

PVAS2. SC

```
while true
@10,0 ??"Enter guardband value:"
accept "N" to guard
```

```
clearall
clear
view "sep94g"
red=true
;guard=0. 5
redoff=-1. 8+guard
redon=-1. 8
trans=0
count=0
total=0
scan
  total=total+1
  if red then
    count=count+1
    if ([Cross] > redoff) then
      red=false
      trans=trans+1
    endif
  else
    if ([Cross]<redon) then
      red=true
      trans=trans+1
      count=count+1
    endif
  endif
endscan
clearall
clear
@2,0 ??"Guard = ",guard," m/s"
@4,0 ??" Number of transitions = ",trans
@6,0 ??" Red Percent = ",100*count/total
@8,0 ??" Green Percent = ",100*(total-count)/total
endwhile
```

PVAS3. SC

```
while true
@10,0 ??"Enter guardband value:"
accept "N" to guard
@12,0 ??"Enter minutes to average:"
accept "S" to Nmin
clearall
clear
view "may95g"
array cw[20]
```

```
point=1
mpoint=21-Nmin
trans=0
count=0
ma=0
total=0
bad=0
short=0
scan
  total=total+1
  if(total=1) then
    cwa=[Cross]
    for i from 1 to 20
      cw[i]=cwa
    endfor
    if(cwa>0. 0) then
      aright=true
    else
      aright=false
    endif
  else
    point=point+1
    mpoint=mpoint+1
    if point>20 then
      point=1
    endif
    if mpoint>20 then
      mpoint=1
    endif
    cw[point]=[Cross]
    cwa=cwa+(cw[point]-cw[mpoint])/Nmin
    count=count+1
    if aright then
      if(cw[point]<-1. 8) then
        bad=bad+1
      endif
      if (cwa<-guard) then
        if count<11 then
          short=short+1
        endif
        aright=false
        trans=trans+1
        count=0
      endif
    else
```

```
      if(cw[point]>1. 8) then
        bad=bad+1
      endif
      if (cwa>guard) then
        if count<11 then
          short=short+1
        endif
        aright=true
        trans=trans+1
      endif
    endif
  endif
endscan
clearall
clear
@2,0 ??"Guard = ",guard," m/s","  Averaging =",nmin," minutes"
@4,0 ??" Number of transitions = ",trans
@6,0 ??" Bad = ",bad
@8,0 ??" Short = ",short
endwhile
```

APPENDIX C - SAMPLE STRIP CHARTS

The following strip charts were generated using the IBM-PC DOS program PSIG48B. EXE, which operates on performance files (see Section 3.1) and generates HPGL/2 output on LPT1 that can be plotted on a Hewlett Packard LaserJet III or later model. The scale factors for the plots are set in the file SETUP. DAT. The sensors plotted are selected from an ASCII file of parameter names. The program, auxiliary files, parameter list files and performance files are in the PERMORM subdirectory of the CD ROM.

Five sample plots are attached; they used the parameter name files:

1. WINDTURB - This plot shows the wind data from the end of the array, along with temperature and relative humidity. Wake vortices are noted in the data from 0140 to 0415 hours. Note that the wind algorithm of Section 3.2 will fail to exclude the influence of the wake vortices for 0140-0230 hours where vortices reached both ends of the array.

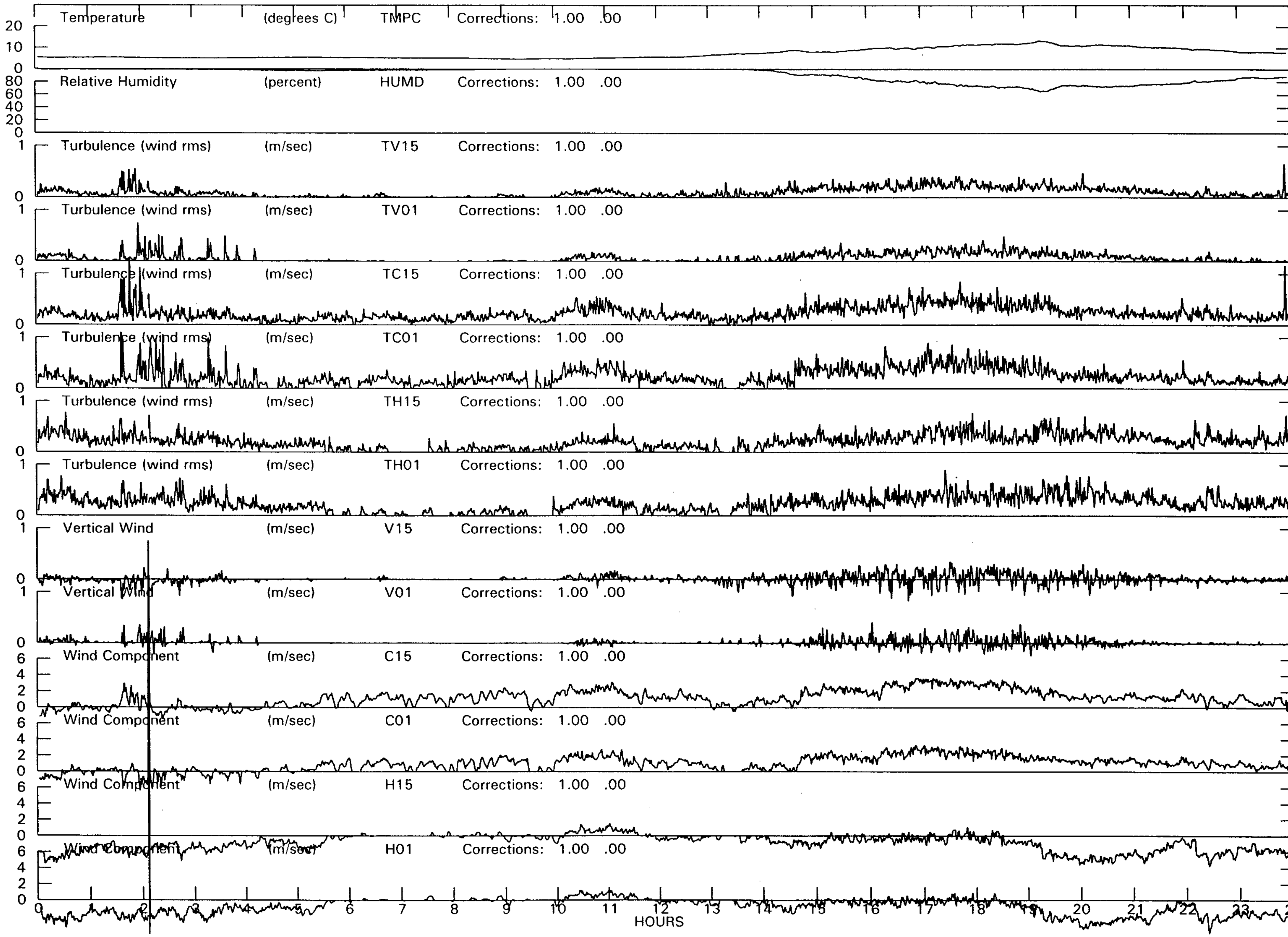
2. CWIND - Crosswinds across the array. Note the opposite sign of the wake vortex crosswinds on the two sides of the array between 0300 and 0400 hours.

3. CTURB - Crosswind turbulence across the array.

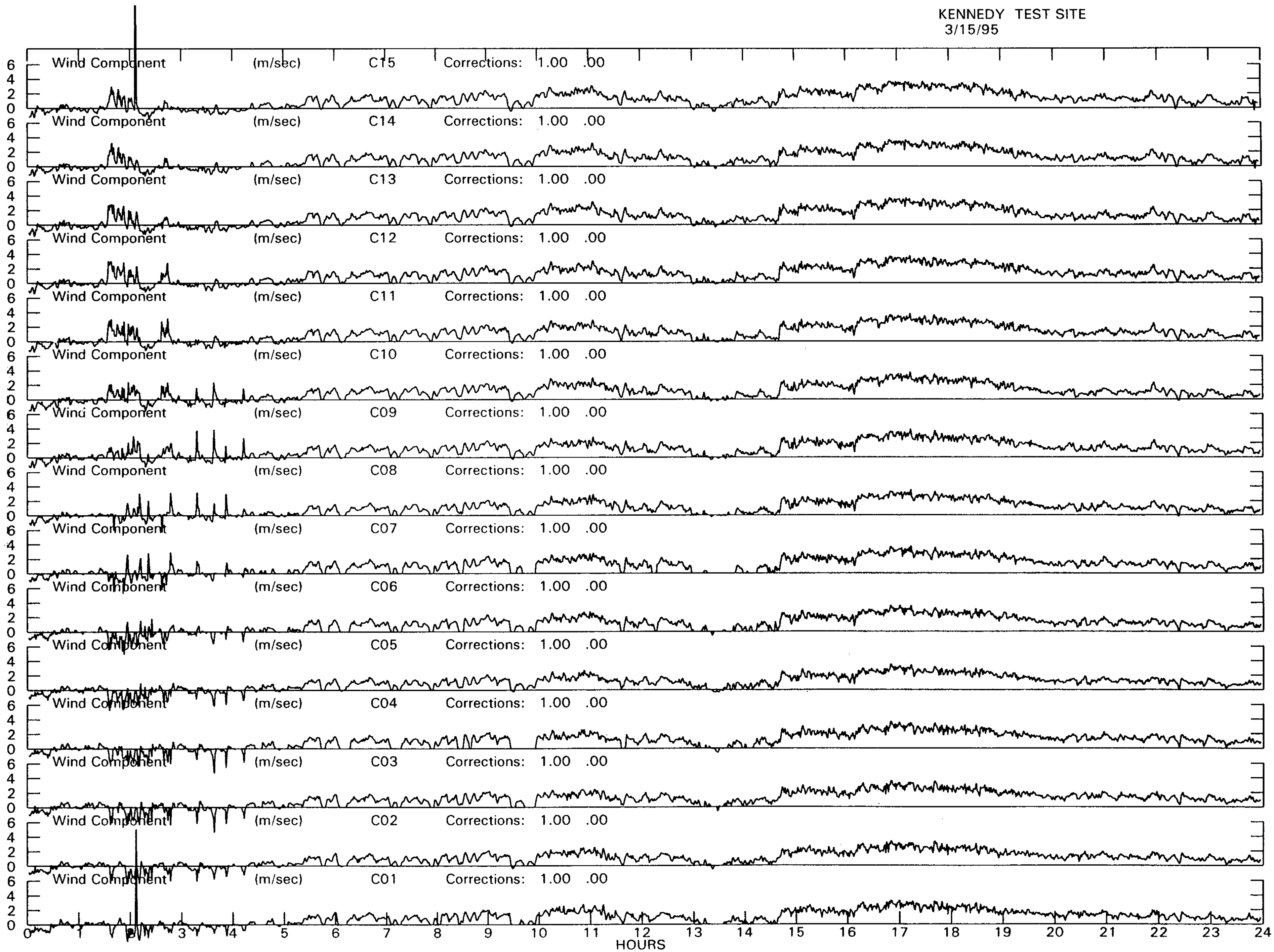
4. VWIND - Vertical winds across the array. Note that wake vortices are more clearly shown in vertical wind than crosswind, since the mean vertical wind is zero.

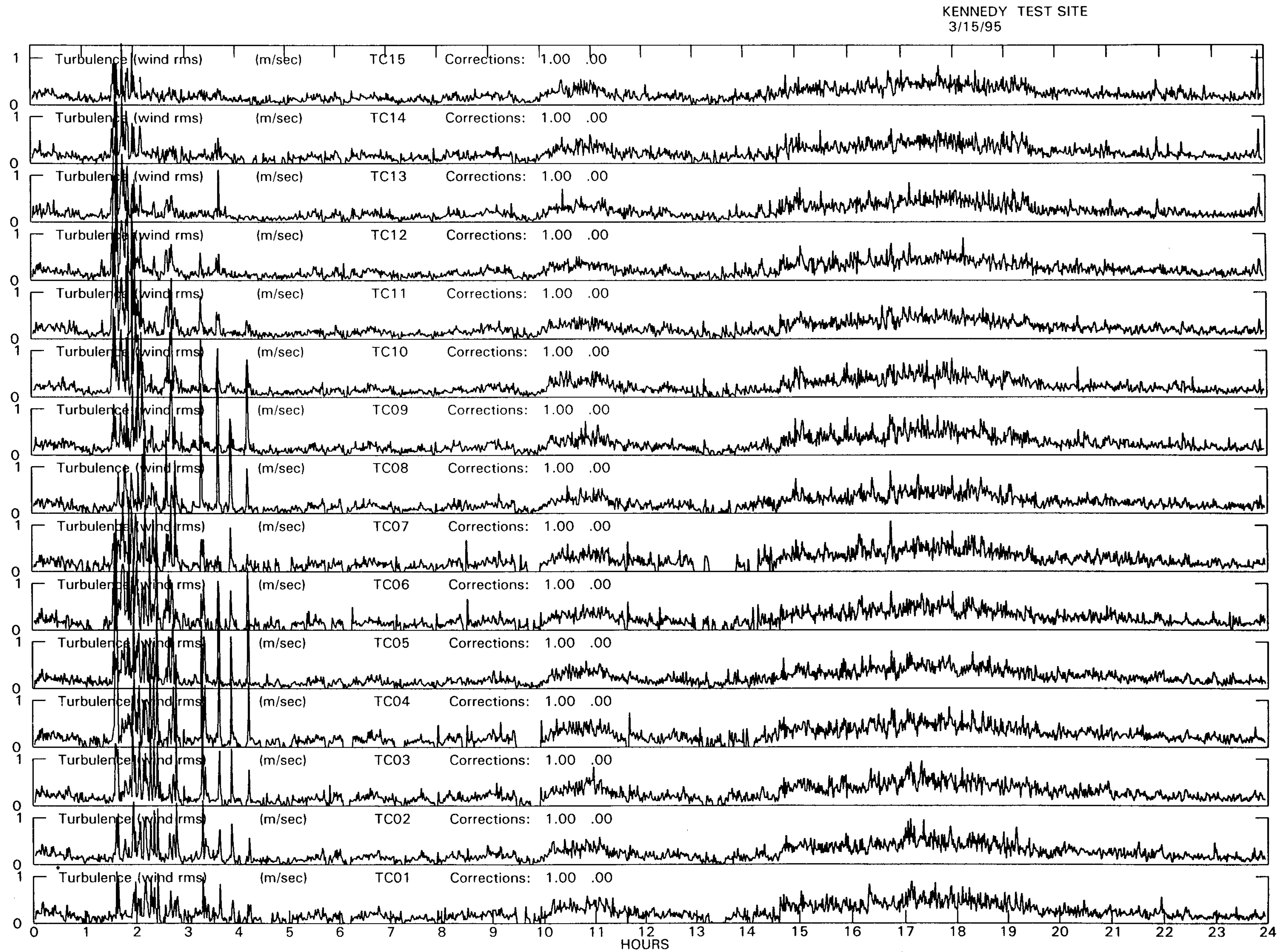
5. VTURB - Vertical wind turbulence across the array. Note positive vortex signatures.

KENNEDY TEST SITE
3/15/95

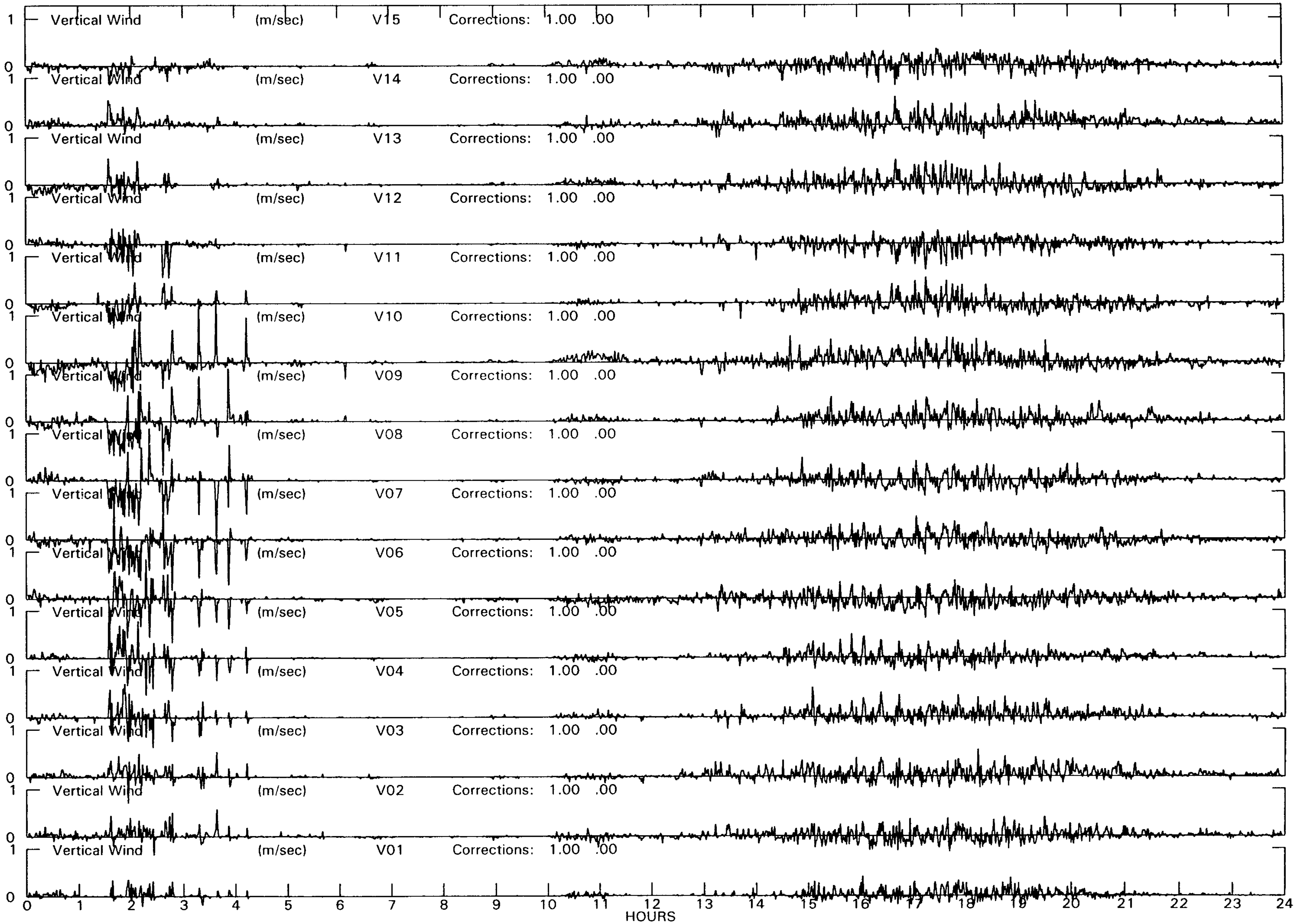


KENNEDY TEST SITE
3/15/95

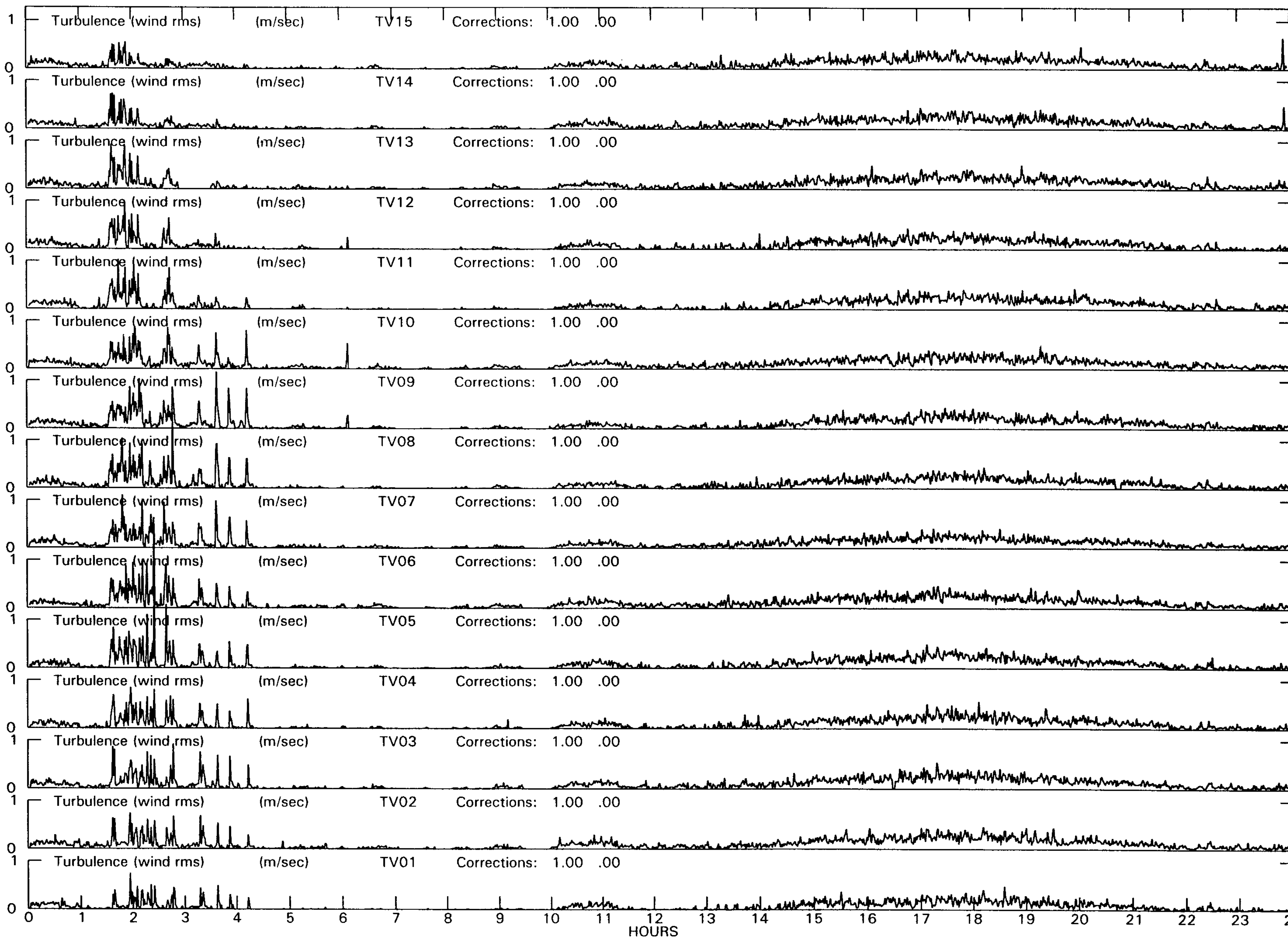



KENNEDY TEST SITE
3/15/95
Turbulence (wind rms) (m/sec) TC15 Corrections: 1.00 .00
Turbulence (wind rms) (m/sec) TC14 Corrections: 1.00 .00
Turbulence (wind rms) (m/sec) TC13 Corrections: 1.00 .00
Turbulence (wind rms) (m/sec) TC12 Corrections: 1.00 .00
Turbulence (wind rms) (m/sec) TC11 Corrections: 1.00 .00
Turbulence (wind rms) (m/sec) TC10 Corrections: 1.00 .00
Turbulence (wind rms) (m/sec) TC09 Corrections: 1.00 .00
Turbulence (wind rms) (m/sec) TC08 Corrections: 1.00 .00
Turbulence (wind rms) (m/sec) TC07 Corrections: 1.00 .00
Turbulence (wind rms) (m/sec) TC06 Corrections: 1.00 .00
Turbulence (wind rms) (m/sec) TC05 Corrections: 1.00 .00
Turbulence (wind rms) (m/sec) TC04 Corrections: 1.00 .00
Turbulence (wind rms) (m/sec) TC03 Corrections: 1.00 .00
Turbulence (wind rms) (m/sec) TC02 Corrections: 1.00 .00
Turbulence (wind rms) (m/sec) TC01 Corrections: 1.00 .00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
HOURS

KENNEDY TEST SITE
3/15/95



KENNEDY TEST SITE
3/15/95



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